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Experimental gaming for Command, Control and Communications

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Introduction

A series of annual experiments in Command, Control and Communications have been held at NPS over the last three years. These experiments have been sponsored by the Defense Communications Agency under the auspices of the Joint Directors of Laboratories C3 Basic research program. These experiments have used a computer-aided wargame and a large number of players to provide data for investigation of C3 issues which are of broad interest to the community. This paper describes those experiments, details the data gathering methods of the most recent experiment, and provides an introduction to the results obtained when the Headquarters Evaluation and Assessment Tool (HEAT) methodology developed by Defense Systems Incorporated (DSI) is applied. DSI has supported the experiments and analyzed the data in each year. A comprehensive summary of their work is [1]. The issues addressed to date include connectivity, centralization and command role. The data for each experiment include thousands of observations gathered through a month of experimentation representing several thousand officer subject hours in realistic battle command situations.

For each of the experiments in the series a consensus was reached by the three participating organizations, DCA, DSI and NPS as to the specific subject which would be investigated. In general the investigations concerned command and control structures and their performance, how these structures might be modified by design, or how they might change during the course of a series of stressful events. A constraint was that the computer laboratory environment would allow the games to be replicated, and that resultant data from a series of iterations would support statistical analysis. During the series of experiments it was found that the team was able to present realistic problems using the wargaming system, that the subjects (who were officer-students) made reasonably effective decisions, and that a series of short gaming events produced data which could be analyzed statistically. In addition, the experiments could be controlled to reduce the effects of learning and to explore minor changes in the command and control system architecture which was being simulated. The wargame (hardware and software) used is the Navy's Interim Battle-Group Tactical Trainer (IBGTT) developed by the Naval Ocean Systems Center and currently in use by the Tactical Training Group, Pacific. Generalization from these results is of course dangerous, but a continuity of results over a considerable scale (one to four carrier groups) and range of scenarios has been shown (Sea of Japan, Persian Gulf and Norwegian Sea).

C2 Laboratory Experiment - Connectivity

The first experiment of the series was an attempt to corroborate Soviet [2] findings which indicated that the command effectiveness as measured by the speed and correctness of its decisions, of a battlefield headquarters is influenced by the command structure. In the NPS Wargaming Analysis and Research Laboratory (WAR lab) a set of military problems were presented to subjects who were organized in increasingly connected command structures ranging from star to fully-connected. This experiment, conducted in November 1983, utilized the Navy's Combined Warfare Commander (CWC) concept to represent the distributed headquarters of a hypothetical battle group in the Sea of Japan. The data collection plan was designed to allow the use of HEAT measures to quantify the activity of the headquarters units regardless of their relationship and ability to communicate with the other headquarters in the command. For example, one measure was time to complete a planning cycle. The results of this experiment are reported by the authors in a paper in the ONR-MIT Theory of C3 Conference series, Ref. [3] and by DSI. DSI could not discount the findings by the earlier Soviet researchers but did indicate that there were differences in speed of action and error rates depending upon the command linkages and communications structure, as shown in Table 1 from the ONR-MIT paper.

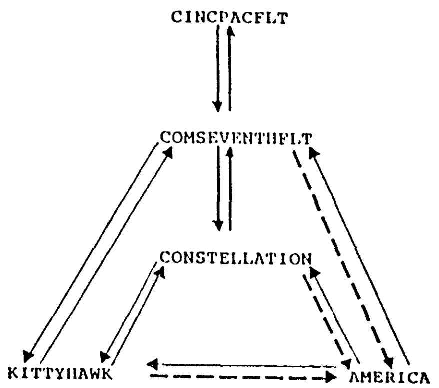
Table I

* Star structures are slightly faster than fully-connected structures but not to a statistically significant level.
* (Did not contradict Soviet findings.)
* The fully connected structure was able to reach a decision more often than the star structure but the decision error rate was about the same.
* (Did not contract Soviet findings.)
* Fully connected structures were always slower to initiate hostilities mistakenly than were other structures.
* (An independent finding.)

Organizational Responsibility - Centrality

The second in a series of experiments was conducted in October of 1984. The objective was to examine alternatives in the degree of centrality of information and decision making in a multiple-carrier battle force. For this experiment a headquarters was created which represented a battle force of three carrier battle groups. They operated together in an environment which was rich with potential adversaries around the Straits of Hormuz and Persian Gulf. The design allowed the command responsibilities to be varied such that each carrier was responsible for every event in its vicinity, known as geographic or decentralized responsibility, or only for specific types of response over the whole area of conflict, known as functional or centralized. A two-way electronic mail system was added for this experiment to provide controlled communications including jamming, which was an experimental variable. Figure 1 represents the basic organization tested. The relative performance against small, discrete threat problems and against larger, complex threats were hypothesized as shown in Figure 2. Forty-five players were arranged into teams such that each set of three teams experienced six variants of the game according to the experimental design shown as Figure 3. The end game was varied to avoid learning effects. The data that was generated was again analyzed and HEAT scores were assigned where appropriate. The results are shown in Figure 4. This experiment was one of the first attempts to analyze the organizational interaction of three aircraft carriers, simultaneously dealing with the same series of problems, using analytical methods with man in the loop. The effort was therefore significant in its own right and formed a bridge to the experiment of 1985.

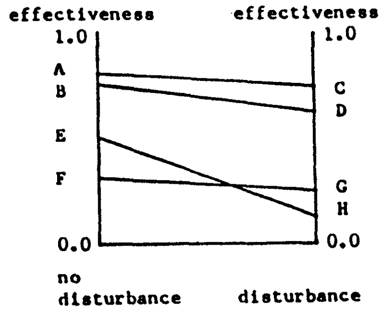
EXPERIMENTAL COMMUNICATIONS AND DISTURBANCES



- TWO-WAY ELECTRONIC MAIL COMMUNICATIONS NETWORK
- DASHED LINES INDICATE A TYPICAL DISTURBANCE

FIGURE 1

C^2 organizational experiments: anticipated findings



A - geographic, discrete
B - functional, discrete
C - geographic, discrete
D - functional, discrete
E - functional, complex
F - geographic, complex
G - geographic, complex
H - functional, complex

Figure 2

Sequence of Scenario, Structure, Disturbance, and End-Game

Group 1	Group 2	Group 3
Iraq functional clear comm attack	USSR geographic clear comm intimidate	Iran & Iraq geographic clear comm provoke
Iran geographic clear comm attack	Iran geographic clear comm provoke	nobody functional clear comm intimidate
Iraq & USSR functional disturbance intimidate	Iraq & USSR functional disturbance attack	Iraq geographic clear comm attack
Iraq & Iran geographic disturbance attack	nobody geographic disturbance intimidate	Iraq & USSR geographic disturbance attack
USSR geographic disturbance provoke	Iraq & Iran functional clear comm attack	Iran functional disturbance attack
nobody functional clear comm provoke	Iraq functional disturbance provoke	USSR functional disturbance provoke

Figure 3

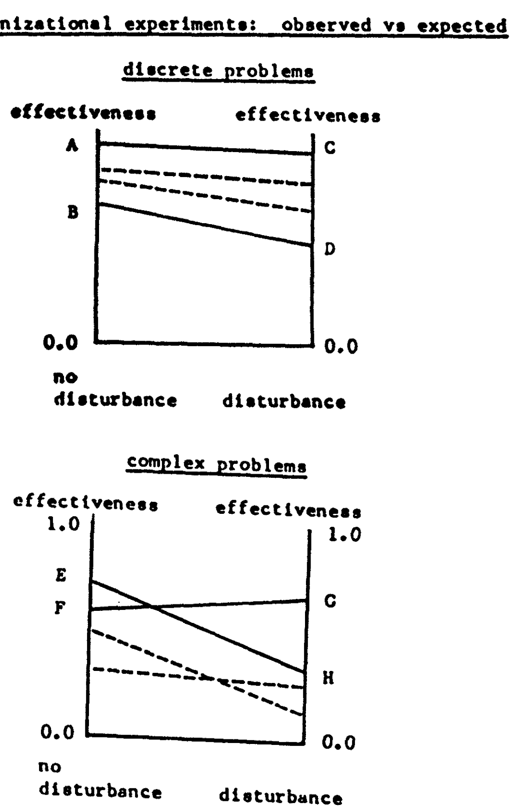


Figure 4

Taking the Fleet Exercises to the Laboratory - Role Experiment

Navy operational fleet commanders are interested in obtaining answers to emerging questions of strategy and tactics such as how to fight a multiple carrier battle force. In the past large-scale exercises have been used to good advantage to seek answers to some of these questions. Now, however, it is frequently the case that the full-scale exercise costs limit the number of these exercises that may be conducted. As a substitute it has been proposed that the large computer-aided wargaming facilities now becoming available on both coasts under fleet control may be used as a substitute for some exercises. To a limited degree it may be possible to create tests for the same questions in the laboratory which has additional advantages. In 1985 a large exercise was run under fleet sponsorship which involved a battle force of three aircraft carriers. The third laboratory experiment in our series was designed after the earlier exercise with the possibility that the results of the two endeavors would be comparable. The WAR Lab simulation provided to the subjects a representation of the same friendly forces and challenged them with the same threat environment as did the exercise which had been conducted both at sea and in-port in a series of Battle Force-Inport Training (BFIT) exercises. Although the laboratory is much less realistic than the exercise, it offers the following advantages discussed below, ease of data extraction and design flexibility so that a range of alternatives can be explored in a variety of environment scenarios. A high comparison of the experiments and the exercises are shown as Table II.

Table II. Comparison of NPS Experiments and Fleet BFITs

	NPS Experiments			Fleet BFITs	
	Connectivity (1983)	Centrality (1984)	Role (1985)	2-85	1-86
Representation of Combat					
Degree of realism	2	2	2	4	4
Degree of control	3	3	3	2	2
Contextual Variables					
HEAT cycle frequency (per hour)	0.67	4.0	4.0	3.1	3.3
Type of warfare	Conventional	Conventional	Conventional	Conventional	Conventional
Friendly units monitored	31	84	154	236	398
Enemy units monitored	55	39	155	77	118
Problem complexity	12	12	12	10	10
Problem subtlety	9	18	4	4	4
Defining Variables					
Echelon	BF/BG	BF/BG	BF/BG	BF/BG	BF/BG
Role type	Objective-specific	Objective-specific	Objective-specific	Objective-specific	Objective-specific
Subordinates	31	84	154	28	67
External nodes	3	3	3	9	7
Internal nodes	4	4	5	5	5
Links per internal node	3.75-5.25	5.25	6.2	7	7
Space distribution	Dissociated	Dissociated	Dissociated	Dissociated	Dissociated
Connectivity	50-100%	100%	100%	100%	100%
Capacity Variables					
Personnel	4	12	13	40	40
Grade of planners	03-05	03-05	03-05	03-07	03-07
Unit experience	0	0	0	0-1	0-2
ADP usage	Monitor, Inform	Monitor, Inform	Monitor, Inform	Monitor	Monitor
External linkage reliability	100%	100%	100%	98+%	98+%
Internal linkage reliability	100%	96%	94%	98+%	98+%
External linkage capacity	Data	Data	Data	Image	Data
Internal linkage capacity	Text	Text	Text	Voice	Voice
External linkage medium	Wire	Wire	Wire	BLOS radio	BLOS radio
Internal linkage medium	Wire	Wire	Wire	BLOS radio	BLOS radio
Dependent Variables					
HEAT cycle time (directives) (min.)	4	--	--	23	11
Understanding correctness (enemy intent)	50%	65%	75%	100%	100%
Understanding completeness (enemy intent)	71%	--	78%	100%	67%
Prediction completeness	--	--	21%	34%	13%

The lessons learned in the 1984 experiment provided guidance for the design of the organization which would be simulated. Although we investigated the geographic and functional organizations in the previous year, it appeared that a hybrid would be the more logical choice for a commander faced with the resources and the problems of operating a three-carrier battle group. The design then included half the sessions run with the strike coordinator being a functional entity and the Allied ASW coordination being run in a functional manner in all sessions. Figures 5 depicts the organizational charts for these designs.

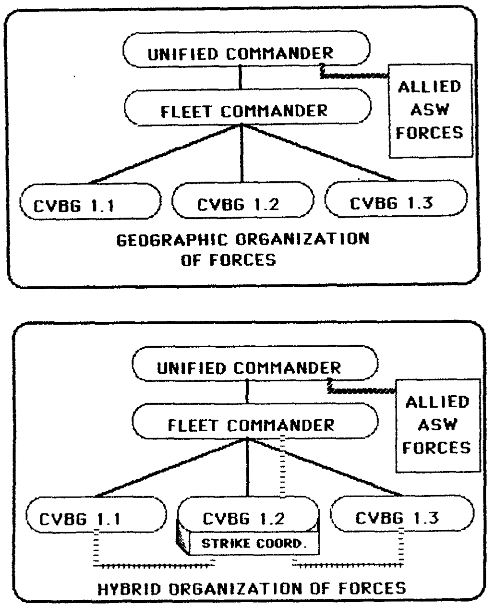


Figure 5

The quantity of data generated by any single game is large. To provide the reader with the scope of material it is necessary to understand the make up of one command position. Figure 6 shows this configuration as a collection of three terminals which interact with the main computer and a geotactical display which shows the force layout in planform. During a game, orders to control combat units are entered at the player position and automatic acknowledgements are received, including attempted actions which cannot be supported at that time. Information is extracted from the game data bank by single keystroke at the status position. Communications are sent and received at the comm position.

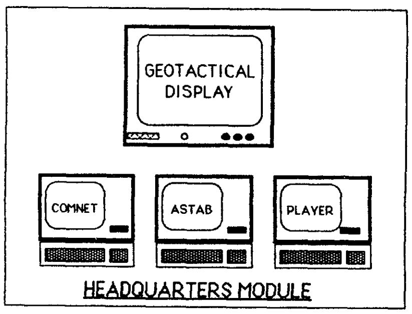


Figure 6

Through modification of the electronic mail software of the previous year, we were able to provide structure to the communications between headquarters such that the intent of the decision makers could be more easily analyzed with pre-formatted reporting requirements. In addition, the software provided copies of each individual message from each headquarters unit and aggregate statistics about rates of activity at each node in the network. Moreover, by the addition of observers at each cell we were able to quantify the activity of each cell to a greater degree than in the past. Each observer was armed with a laptop computer which was preprogrammed to accept single keystroke entries of seven items of interest to the HEAT analysts. The article are shown in Table II. The observers could then rapidly record events that would show up in no other record and these events could be compared with other records. A time-dated series of observations could then be dumped to the host computer.

The complete record of the headquarters activity consists of (1) the player record, which is all the orders entered at this terminal and the computer responses, (2) the commmunications record, which is every message sent by the terminal and an analysis of the terminal players time to generate messages and to respond to incoming messages throughout the game, and (3) the file of observer responses. These constitute a headquarters packet. For each game there were three headquarters packets and, in addition, there is a complete file of umpire orders which includes the moves of the opposition, and a file containing a record of engagements, damage, and the speed at which the game was progressing. Figure 7 depicts orders which might be entered by a player, in this case, the umpire control console operator, and appropriate responses from the software about recent orders.

```
_REMNET$DUA2:[SDC]PAGE.DOC;1                                    4-JUN-1

 BEARING 179 RANGE 79
(010719) Order executed.
FOR ECHO1 FIRE 4 SSN12 CRUISE (missiles) BEARING 179 RANGE 55
(010720) Order Entered.
(010720) ----
(010720, Copy of BLUE1) MP601 cannot intercept AA022
(010720, Copy of BLUE1) VW001 cannot intercept AA026
(010720, Copy of BLUE2) OMAHA Vector to 279 SPD 31 to travel 16 NMI in
                        31 min.
FOR ECHO1 DEPTH 250 TIME 10
(010720) Order Entered.
END (auto logout?) YES
(010720) Order Entered.
(010721) ----
(010721, Copy of BLUE1) PAUL cannot take invalid track number AA022
(010721, Copy of BLUE2) VF703 cannot take invalid track number BA029
(010721, Copy of BLUE3) STARK cannot intercept CS001
(010721, Copy of ORANGE1) 1 missiles successfully fired by ECHO1. 0 failed.

Wargame Exercise Halted.
```

Figure 7.

Figure 8 is an aggregated listing of all orders entered by all players from which move and countermove can be traced for postgame analysis. Figure 9 (TOP) is an example of a preformatted message which is presented to a communicator and a message which results from the use of the system (bottom) complete with time tags which have been added by the software. Figure 10 aggregates the results of many messages between available nodes in the category "throughput time", which is the sum of construction time, transmission and reception time increments. Observations made by observers which were colocated with the players in each headquarters cell are shown in Figure 11. Various codes depict significant events as shown in Table III. Ultimately the results of all these messages, game orders and decisions are

Figure 8

10-

```
_REMNET$DUA2: [SDC]NORTHX.ORD;5

 5 Views

View  Code
----  ----
  1    91
  2    11
  3    12
  4    13
  5    51
 349)  v2   m25            FOR FARGT BLIP ON
 350)  v2   m25            FOR CORAL COURSE 90
 351)  v2   m25            FOR CORAL SPEED 35
 352)  v2   m25            FOR WHTNY STATION 0 CORAL 7
 353)  v4   m25            FOR 1.3.0.0 EMCON SONAR
 354)  v4   m25            FOR LUCE EMCON RADIA
 355)  v4   m25  1 of 4    FOR SARA LAUNCH 4 A6E KILL3 90 300 20000
 356)  v4   m25  2 of 4    FOR SARA LOAD 2 SHRIK 2 WALLI
 357)  v4   m25  3 of 4    FOR KILL3 PROCEED COURSE 90 30
 358)  v4   m25  4 of 4    FOR KILL3 MISSION STRIKE
 359)  v4   m25  1 of 4    FOR SARA LAUNCH 1 KA6D KA6D3 90 250 20000
 360)  v4   m25  2 of 4    FOR SARA LOAD
 361)  v4   m25  3 of 4    FOR KA6D3 PROCEED COURSE 90 23
 362)  v4   m25  4 of 4    FOR KA6D3 MISSION AIRTANKER
 363)  v2   m25  1 of 4    FOR BODO LAUNCH 1 P3C MP111 10 250 25000
 364)  v1   m38            RELOCATE ECHO1 -9000 100
 365)  v1   m38            TIME 120
 366)  v1   m38            RELOCATE CF000 7000 1330
 367)  v1   m38            RELOCATE CF001 7000 1500
 368)  v1   m38            RELOCATE CF002 7000 1600
 369)  v1   m38            RELOCATE VW000 7000 1600
 370)  v1   m38            RELOCATE BROWN 7100 1300
 371)  v1   m38            RELOCATE MP600 6700 1200
 372)  v1   m38            RELOCATE VF700 6730 900
 373)  v1   m38            FOR VF700 SPEED 0
 374)  v1   m38            FOR VF700 REPLENISH 2000 FUEL
 375)  v1   m38            RELOCATE VF701 6715 900
```

Figure 9

SAMPLE PREFORMATTED DATAFILE

```
BLUE PLANNING MESSAGE
1. ORANGE OPTION (1) ______________________________
                 (2) ______________________________
                 (3) ______________________________
   ORANGE INTENT (1) ______________________________
                 (2) ______________________________
                 (3) ______________________________
   OTHER CONTINGENCIES ____________________________
   ________________________________________________
2. BLUE OPTIONS  (1) ______________________________
                 (2) ______________________________
                 (3) ______________________________
   ASSESSMENTS OF OPTION (1) ______________________
   ________________________________________________
   OPTION (2) _____________________________________
   ________________________________________________
   OPTION (3) _____________________________________
   ________________________________________________
3. BLUE PLAN (OFFENSIVE, DEFENSIVE, SELECTION OF PRESSURES OPTION)
BT

THIS FILES IDENTIFYING NUMBER IS:    12
THIS MESSAGE IS LABELED: INFO
SORT TIME IS: 11:25:31
ENTRY TIME: 11 25.26  SEND TIME: 11:25:31  ARRIVAL TIME: 11:25:57  READ TIME: 11.29 31
THROUGHPUT:     245 000  DESTINATION:     214.000  PREPARATION:     5 000
FROM: C2F          TO. CINCLNT


010656Z

TO:    CINCLNT
FROM:  C2F


1.  FORWARDED.


010655Z

TO:    STRIKE
FROM.  SARA

INFO:  C2F

SARA LENINGRAD STRIKE ACFT ON THEIR WAY
BT
```

Figure 10

THROUGHPUT TIME

FROM NODES	TO NODES CINCLNT	CORAL	C2F	JFK	SARA
CINCLNT	0.00 0.00	0 00 0.00	3 79 3 88	0 00 0 00	0.00 0 00
CORAL	0.00 0.00	15.52 15.51	3.99 3.99	5.57 7.67	10.36 12.80
C2F	3.75 4.07	5.13 6.59	0.00 0.00	2 82 3.52	7.29 8.97
JFK	0.00 0.00	2.80 3.97	1.97 1.99	7 62 9.17	7.34 8.89
SARA	0.00 0.00	3.50 3.65	2.99 3.36	3.29 3.69	0.00 0.00
STRIKE	0.00 0.00	11.16 11.50	3.72 3.91	5.75 6.54	9.35 11.00
COL. MEANS	3.75	5.26	2.88	3 99	7.91

Table III. Observed Heat Measures

TITLE	DEFINITION	SCALINGS
Received Directive Quality (RDQ)	This measure scores the quality of the directive by whether or not it was understood, and also the action taken by the recipient if the directive was not understood	Not understood, not queried Not understood, queried Understood Incomplete, not queried Incomplete, queried
Surprises Queried (SQ)	This measure scores the action taken by the cell when surprised	Not understood, not queried Queried via status board Queried via talk
Action taken to Influence Orange (AIO)	This measure scores the attempts by BLUE cells to influence ORANGE action	No attempt Attempt
Contingency Coverage (CC)	This measure scores the contingency planning of each cell	Number of contingencies
Orange Options Understood (OOU)	This measure scores the BLUE understanding of the options available to ORANGE	Not understood Understood Partially understood
Orange Intent Understood (OIU)	This measure scores BLUE understanding of ORANGE intentions, or plans	Not understood Understood Partially understood
Blue Predictions (PR)	This measure scores whether or not BLUE cells predicted the outcomes of each alternative action developed	Predictions made/ Not made/Number

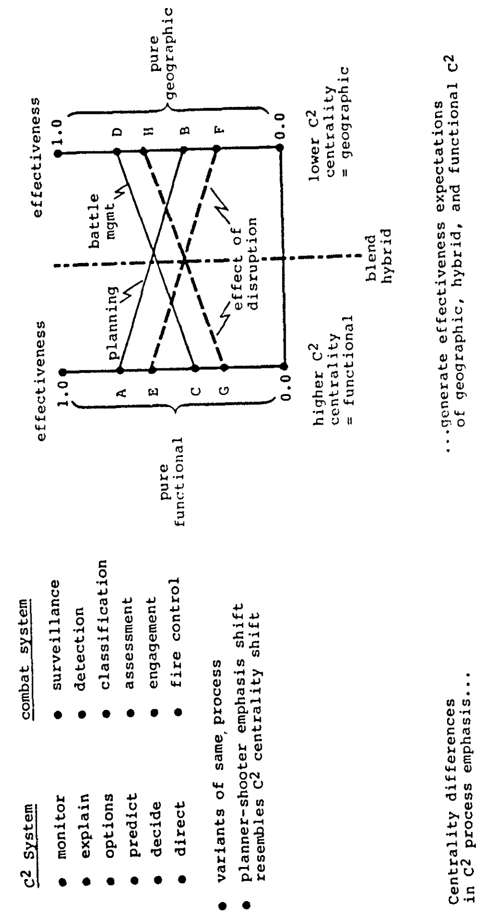
played out by the software and displayed on the game control terminal as shown in Figure 12. By analyzing these results such factors as missed opportunities, weapons expenditure rates, force exchange ratios and the effect of feints or information delays can be determined. The design team settled on 16 runs as providing a realistically sufficient experiment which ultimately produced 64 data packets for analysis using HEAT.

Figure 11

```
_REMNET$DUA2: [SDC]A312PG.DAT;1

 1 08:02:38 CM 010624 A31C22F JEFF
 2 08:22:40 CM 0625 C2F/STRIKE
 3 08:23:09 CM PLAN TOGETHER
 4 08:26:43 OO 0630 U
 5 08:29:14 CC 0632 ASIGN RESPON
 6 08:29:51 CM THROUGH OUT FLEET
 7 08:43:01 RD 0644 U FM STRK
 8 08:45:03 CC 0646 DIR FLTS
 9 08:45:36 RD 0647 U FM CINCLNT
10 08:48:59 RD 0649 U FM CBG3
11 08:49:52 SQ 0649 QS SURF SUB
12 08:51:40 AI 0650 DIR CBG3 AT
13 08:52:04 CM SURF SUB
14 08:55:37 OO 0652 U SURF SUBS
15 08:58:30 RD 0655 U FM CBG3
16 09:03:04 OI 0657 U
17 09:04:30 CM CORRECTION TO ABOVE
18 09:04:44 CM C2F DECOYED AWAY
19 09:07:13 CC 0659 QUERY CBG1
20 09:07:31 CM ACTION AG. ORG SUR.
21 09:08:54 OO 0700 NN ORG AC OUT
22 09:10:42 RD 0701 U FM CINCLNT
23 09:20:23 OI 0705 PU
24 09:21:41 OI 0705 U INBOUND CRS
25 09:22:05 CM GAME STOP

 1 08:26:08 CM 0624 A31C2J CHUCK
 2 08:26:57 CM 0625 PLN PREDETERM
 3 08:27:24 CM 0625 CDR INV PLN
 4 08:36:33 CM 0640 DROP ESM TRCKS
 5 08:53:00 SQ 0650 NN SUB
 6 08:58:23 CM 0653 DET SUB TOO LT
 7 08:59:41 SQ 0655 HOST ESM DET
 8 09:01:53 SQ 0656 HOST AC DET
 9 09:03:18 OI 0657 U
10 09:05:00 CC 0657 DIR AC INTC AC
11 09:06:12 RD 0658 U
12 09:14:37 AI 0702 LNC STK MEMANK
```

Figure 12

```
_REMNET$DUA2:[SDC]PAGE.DOC;2                                                4-JUN-1986 11:

   BUSY     AVG     TIME   CYCLE    CYCLE    ZULU     LEN      CPU
 SECONDS   BUSY     SPEC   COUNT     NUM     TIME    CYCLE     TIME
 -------  ------   -----   -----    -----   ------   ------   ------                    2

:   1.09   0.843     20      20       19    011149    20.06    1.460
:   1.12   0.856     20      21       20    011150    19.95    1.180 ^ allow= 1    neu
! Air to Air.....XF009 Attacking AF001 Not in range
! Air to Air.....BF009 Attacking ZF006 Not in range
! Air to Air.....ZF009 Attacking BF007 Not in range
:  22.91   1.987     60      33       32    011202    59.90   10.490
! Air to Air.....AF000 Attacking XF000 w/SPAR (Ph=100) 1*  [XF000 down]  Grand Sl
! Air to Air.....ZF009 Attacking BF007 w/SPAR (Ph=100) 1*  Grand Slam
@ AF000 destroyed
@ XF000 destroyed
@ BF000 destroyed
@ ZF000 destroyed
@ AF001 destroyed
! Air to Air.....XF009 Attacking AF003 Not in range
@ XF003 destroyed
:   2.51   2.598     60      36       35    011205    59.86    2.200
! Air to Air.....XF008 Attacking AF005 Not in range
! Air to Air.....AF009 Attacking XF008 Not in range
! Air to Air.....XF009 Attacking AF003 Not in range
:   1.64   2.572     60      37       36    011206    59.86    1.500
! Air to Air.... XF008 Attacking AF005 Not in range
! Air to Air.....AF009 Attacking XF008 w/SPAR (Ph=100) 1*  [XF008 down]  Grand S
! Air to Air.... XF009 Attacking AF003 Not in range
@ XF008 destroyed
:   2.40   2.568     60      38       37    011207    59.86    1.490
```



14

Figure 13. Logic of C2 Organizational Experiments

Results of the experiments have been analyzed in four forms which are discussed below.

Within the experimental design, a number of replications, for example, 18 in the geographic design shown in Figure 5, are obtained. The hypothesized results of these cases can be expressed by a figure such as Figure 13 which shows the relative overall combat effectiveness as measured by the exchange ratio of enemy losses to friendly losses. For example, the geographic organization in non-complex scenarios should do best. The results from the applications with these properties can be averaged and the relative ranking against other combinations of scenario and organization can be determined.

Crossovers such as shown where the functional organization deteriorates more under jamming, are particularly interesting. Most of the hypotheses made have been confirmed as shown in Table III.

Another type of analysis has been to prepare a matrix of regression relations for each experiment and even across the experiments. In this approach the data for each case is set up as a row in a matrix and statistical relationships are extracted across the cases. For example, Figure 14 shows the relationship between correct identification of the opponent and the dependent variables message delay and overtures of opponent action. The statistics are reasonable and the signs are correct.

DSI has represented the same regression information can be shown as an influence diagram with the coefficients as shown in the bottom of Figure 14. When the entire matrix of regression results is displayed as in Figure 15, a complex set of relationships can be captured which include the interdependencies of scenario, traffic and headquarters performance on the overall combat performance measure, the exchange ratio.

Figure 14

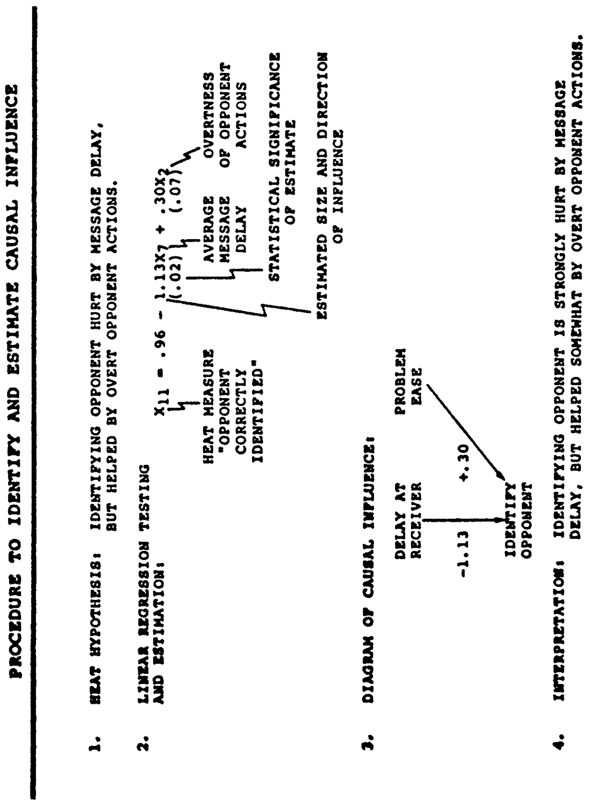
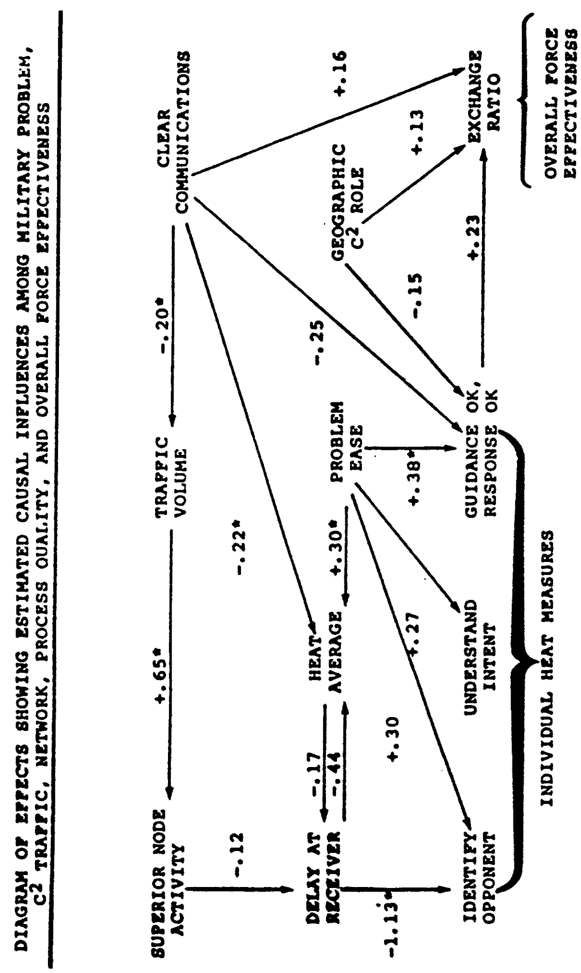


Figure 15



Conclusion

These large-scale trials show that substantial conclusions can be drawn from realistic decision-making experiments in command, control and communications that are controlled by an experimental design.

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